

AD _____

Award Number: W81-XWH-05-1-0133

TITLE: Development of Antigen Presenting Cells for adoptive immunotherapy in prostate cancer

PRINCIPAL INVESTIGATOR: Mathias Oelke, Ph.D.

CONTRACTING ORGANIZATION: Johns Hopkins University
Baltimore, MD 21205

REPORT DATE: December 2008

TYPE OF REPORT: Final

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release;
Distribution Unlimited

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

REPORT DOCUMENTATION PAGE				<i>Form Approved</i> OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE 01-12-2008		2. REPORT TYPE Final		3. DATES COVERED 1 DEC 2004 - 30 NOV 2008	
4. TITLE AND SUBTITLE Development of Antigen Presenting Cells for Adoptive Immunotherapy in Prostate Cancer				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER W81-XWH-05-1-0133	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Mathias Oelke, Ph.D. Email: moelke1@jhmi.edu				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Johns Hopkins University Baltimore, MD 21205				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command Fort Detrick, Maryland 21702-5012				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT While adoptive immunotherapy holds promise as a treatment for cancer and infectious diseases, development has been impeded by the lack of reproducible methods for generating therapeutic numbers of antigen-specific CD8+ CTL. As a result, there are only limited reports of expansion of antigen-specific CTL to levels required for clinical therapy. Therefore, our groups has previously developed artificial Antigen-Presenting Cells (aAPC), made by coupling soluble HLA-Ig and anti-CD28 to beads. These aAPC have successfully been used to induce and expand CTL specific for CMV or melanoma. For the current study we have proposed to used and further developed those aAPC for the generation of prostate cancer specific CTL. Our preliminary data demonstrate that aAPC loaded with the prostate cancer specific antigen EpHA2 have been used to generate functional active prostate cancer-specific CTL from peripheral blood healthy donors. In addition, to overcome the problem of the limited expansion of the prostate cancer specific CTL, we have studied the potential of aAPC to activate and expand antigen specific CTL in vivo. Therefore, we have established an in vivo treatment model of subcutaneous melanoma and demonstrated that aAPC immunization significantly delayed tumor growth.					
15. SUBJECT TERMS aAPC, T cells, EpHA2, PSMA, prostate cancer, CD8, MHC-Ig					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 15	19a. NAME OF RESPONSIBLE PERSON USAMRMC
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (include area code)

Table of Contents

Introduction.....	4
Body.....	4
Key Research Accomplishments.....	12
Reportable Outcomes.....	12
Conclusions.....	13
References.....	13
Appendices.....	N/A

INTRODUCTION

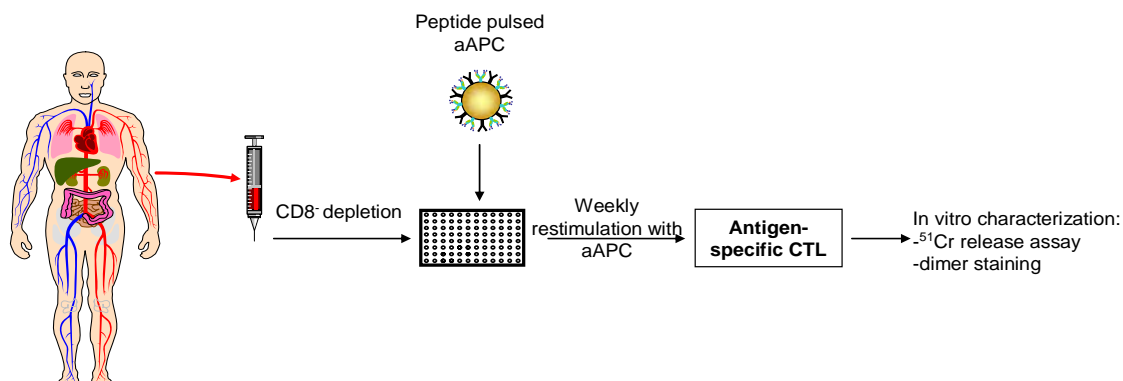
While adoptive immunotherapy holds promise as a treatment for cancer, development of adoptive immunotherapy has been impeded by the lack of a reproducible and economically viable method for generating therapeutic numbers of antigen-specific CTL. Therefore, we are studying use of HLA A2-Ig based aAPC for induction and expansion of prostate specific CTL with the goal of replacing the use of autologous DC for adoptive immunotherapy for prostate cancer. More specifically, we will demonstrate functional efficacy of an “off the shelf” HLA-Ig based artificial Antigen Presenting Cells (aAPC) for inducing and expanding anti-EphA2(58) or PSMA₂₇ prostate-specific CTL. The specific aims are to 1) *optimize aAPC structure and duration of stimulation, and 2) analyze the in vivo function of aAPC-induced CTL.*

These studies will serve as precursor ones for induction and expansion of prostate specific CTL from patients with disease for initiation of adoptive immunotherapy clinical studies as an adjuvant therapy post surgery in the setting of minimal residual disease.

BODY

Adoptive immunotherapy for prostate cancer has been limited by the use of autologous dendritic cells (DC) for expansion of prostate cancer-specific CTL. Recently, we have shown that HLA-A2-Ig based aAPC can be used to expand model antigen specific CTL. To evaluate this approach for use in prostate cancer immunotherapy we proposed to study initially aAPC based *in vitro* expansion of prostate cancer specific CTL using blood from healthy donors and later to evaluate the *in vivo* efficacy of these CTL using a human/SCID mouse model. Over the past award time we have focused on our goals as identified in the statement of work, specifically on optimization of aAPC based T cell stimulation and induction of EphA2 and PSMA specific CTL.

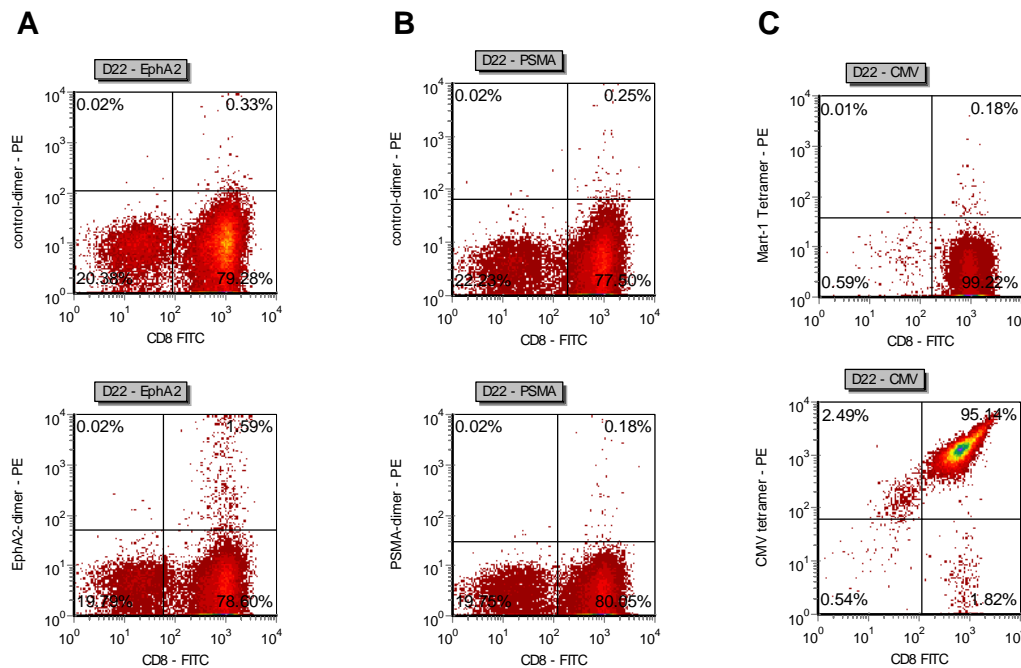
Figure 1: Schematic for aAPC based induction and expansion of induction and expansion of antigen specific CTL



Legend: CD8⁺ T cells were isolated from peripheral blood of healthy donors using magnetic CD8⁺ depletion and co-cultured as shown in the schematic for 4-6 weeks. CD8⁺ T cells were co-cultured with peptide loaded aAPC and harvested once a week. The old beads were removed; T cells were counted and replated and restimulated in 96 well plates with fresh aAPC. After 3 weeks cells were tested as described. Cultures were maintained until the total cell count dropped below 5×10^5 .

We performed aAPC stimulation as described in Figure 1 for multiple donors with PSMA, EphA2 and control peptides like CMV or Mart-1. After several weeks of culture we were able to detect EphA2 specific T cells from 3 donors, whereas no PSMA specific T cells could be generated. At the same time control cultures using Mart-1 or CMV loaded aAPC generated large numbers of highly specific T cells. Figure 2 shows one representative example. The specificity and functionality of the EphA2-specific CTL was confirmed by specific lyses of peptide pulsed target cells in an ^{51}Cr -release assay (Figure 3).

Figure 2: Dimer/tetramer analysis of aAPC induced CTL after 3 weeks of culture

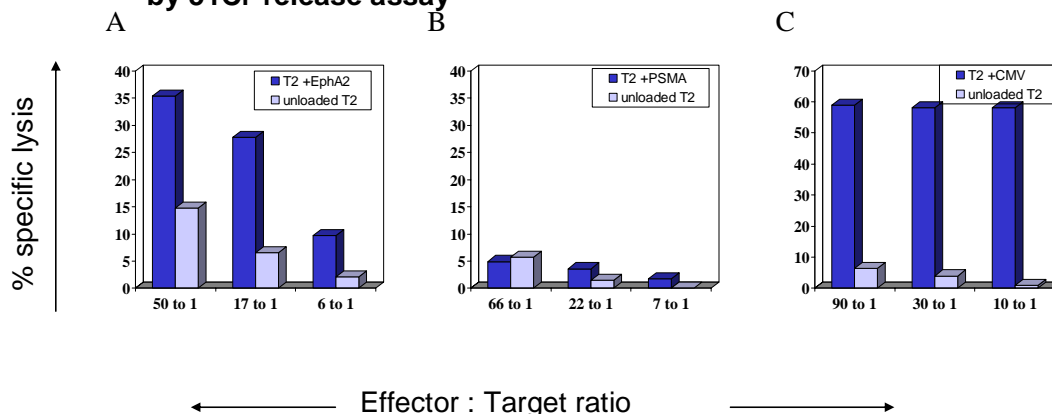


Legend: Figure 2 shows dimer/tetramer staining of T cells which were stimulated for 3 weeks with A) EphA2 loaded aAPC, B) PSMA loaded aAPC and C) CMV loaded aAPC. While the CMV loaded aAPC induced high numbers of antigen specific CTL, aAPC loaded with the prostate cancer specific peptides induce only small numbers using the EphA2 peptide and no specific T cells using the PSMA peptide.

Since the initial approach was not successful for generation of PSMA specific CTL and the generation of EphA2-specific CTL was limited in numbers, we have started to develop second generation aAPC formulations as proposed in the statement of work. B7.1 (CD80) and B7.2 (CD86) on DC are the natural ligands to CD28 on T cells. In addition, it has been reported that the engagement of CD83 on DC with his currently still unknown ligand on T cells can support proliferation and at the same time reduce T cell apoptosis. Our standard aAPC was made by using HLA-A2-Ig in combination with an antibody specific for CD28 on T cells. We postulated

that the natural ligand might have higher affinity or activity and therefore might induce better or stronger costimulation.

Figure 3: Cytotoxic activity of aAPC induced CTL determined by ^{51}Cr -release assay



Legend: Figure 3 shows the cytotoxic activity of aAPC induced peptide specific CTL. CD8^+ T cells were stimulated for 3 weeks with either EphA2 loaded aAPC (A), PSMA loaded aAPC (B) or CMV loaded aAPC (C) and then tested for their cytotoxic activity using a standard ^{51}Cr -release assay. Therefore, total T cells were incubated with either peptide loaded target cells or unloaded target cells as negative control. The given ratios are the ratios from total T cells to target cells.

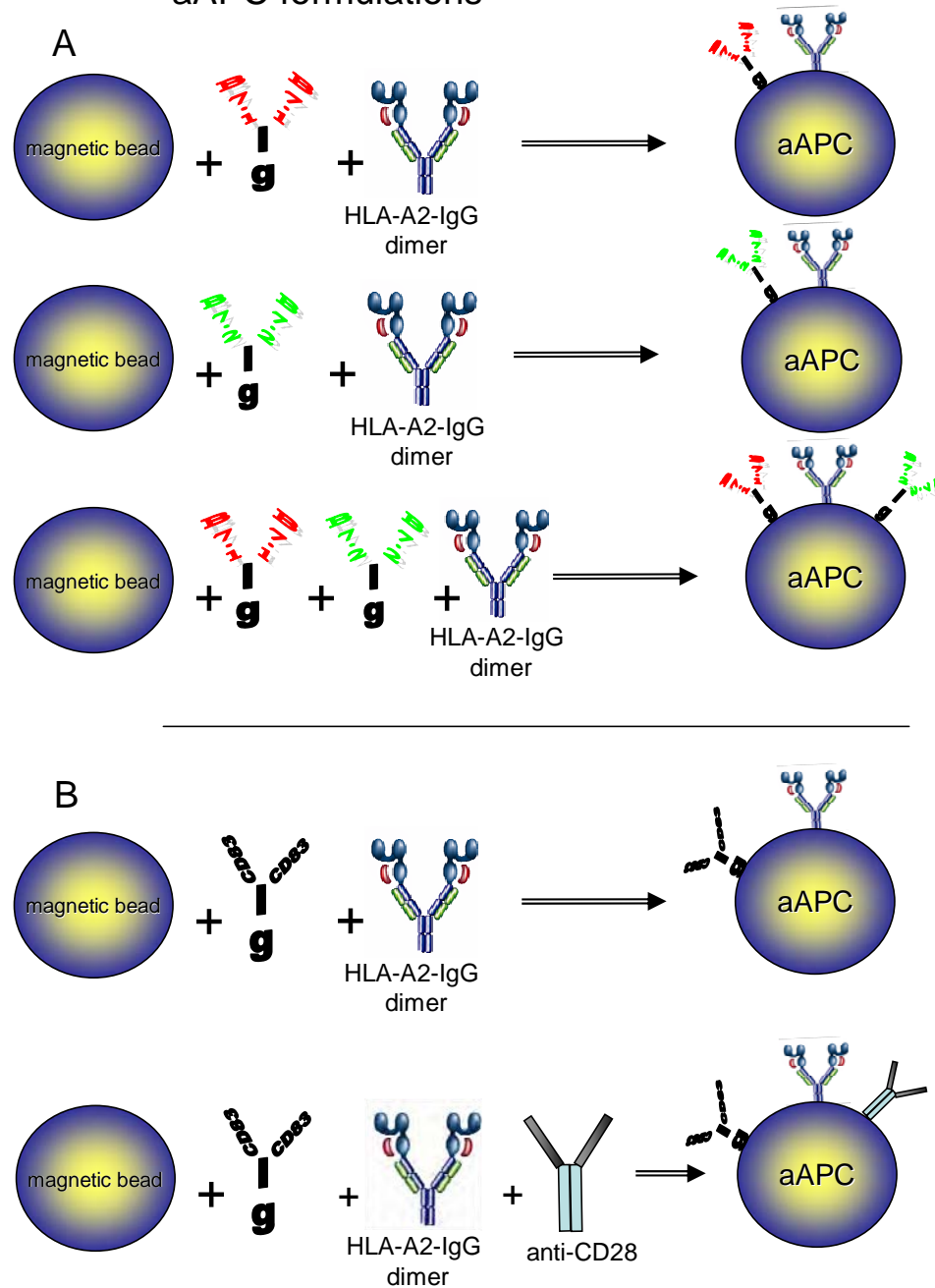
Therefore, we created new aAPC by coating B7.1, B7.2 or B7.1 and B7.2 together with HLA-A2-Ig on magnetic beads. In addition we also generated aAPC by coating magnetic beads with HLA-A2-Ig in combination with CD83-Ig +/- anti-CD28.

Figure 4 shows a schematic of the new created aAPC.

To investigate these new systems we compared the stimulation of the new aAPC with our prototype anti-CD28 based aAPC in either the Mart-1 or in case of the CD83-based aAPC in the CMV system. Both are robust systems which work well for induction of functional antigen-specific CTL as shown in our previous work(1, 2).

We found that in 2 of 3 experiments B7-1 based aAPC generated a higher frequency of antigen-specific CTL than our standard aAPC, figure 5 shows one representative experiment. For one donor we also found a much higher proliferation compared to all other aAPC formulations tested (data not shown).

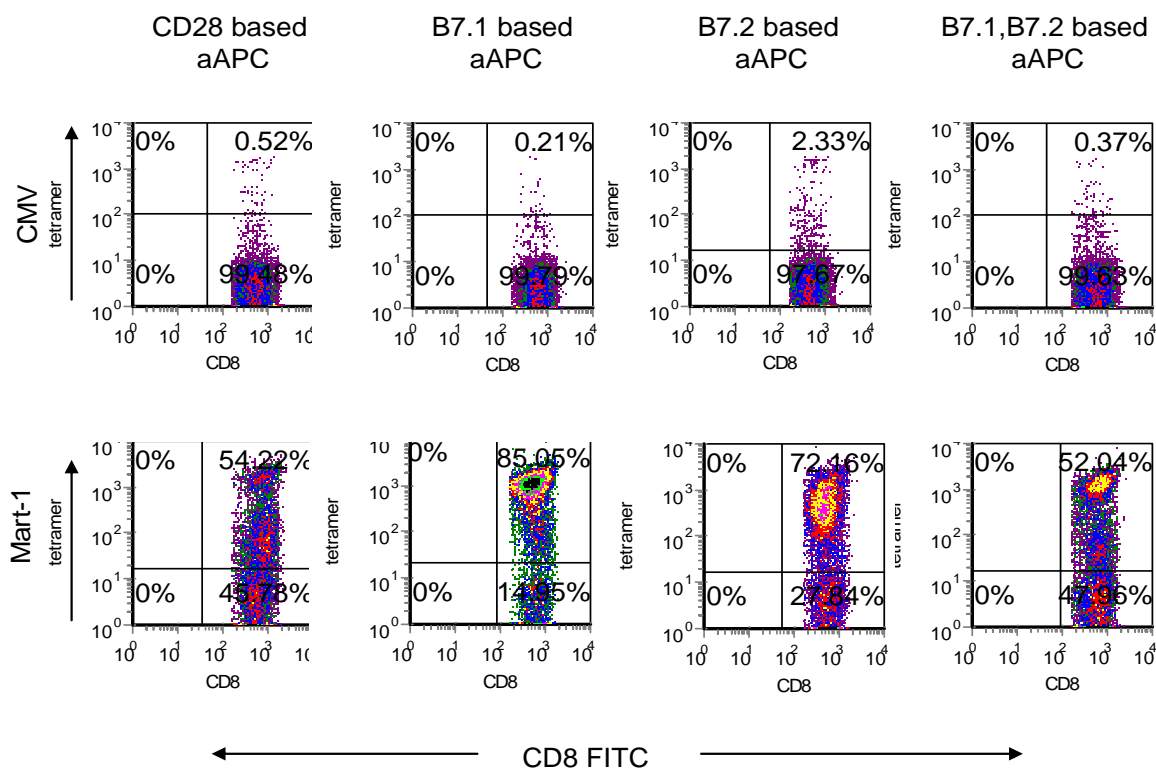
Figure 4: Schematic of second generation aAPC formulations



Legend: Figure 4 shows schematically the structure of various formulations of second generation aAPC. 4A shows aAPC based on the use of B7.1- and B7.2-Ig and 4B aAPC based on the use of CD83-Ig either alone or in combination with anti-CD28.

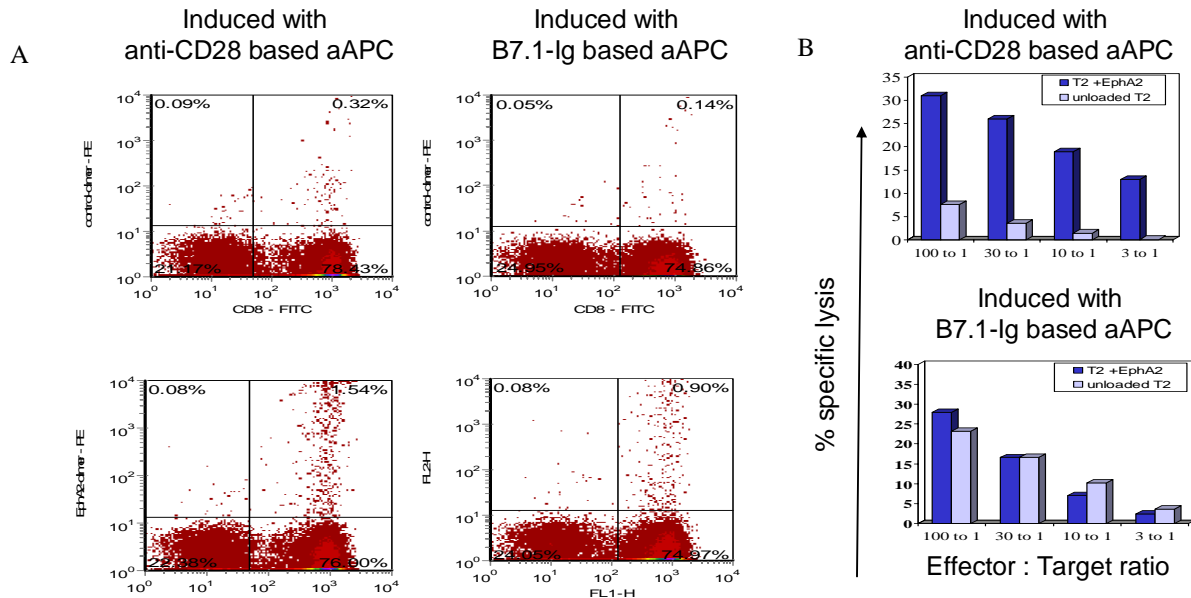
Based on these results we have repeated the experiments to induce prostate cancer specific CTL, comparing our standard anti-CD28 based aAPC with the B7.1-Ig based aAPC (Figure 6). We found that in the first 2 experiments that the use of B7.1-Ig based aAPC did not improve the outcome of the resulting T cell product. While the FACS analysis using antigen-specific dimer staining showed the induction of EphA2-specific CTL at comparable levels to our standard aAPC (Figure 6A), further functional analysis showed high non-specific killing for CTL that were induced with B7.1-Ig based aAPC. In contrast CTL which were induced with our regular anti-CD28 aAPC showed only minimal non-specific killing (Figure 6B). This could be due to the high amount of non-EphA2-specific cells contaminating the culture. Therefore, further experiments, which are currently ongoing, are necessary to analyze the capacity of the B7.1-Ig based aAPC in more detail. This is specifically important these aAPC seemed to be more potent in the well established Mart-1 system.

Figure 5: Tetramer analysis of 2nd generation B7-Ig based aAPC induced CMV specific CTL



Legend: Figure 5 shows a tetramer analysis of Mart-1 specific CTL generated with 2nd generation B7-Ig based aAPC. The different aAPC formulations are indicated on top of each column. The analysis shows that the B7.1-Ig based aAPC induced the highest frequency of antigen specific CTL. As negative control staining with the non-specific CMV tetramer was used.

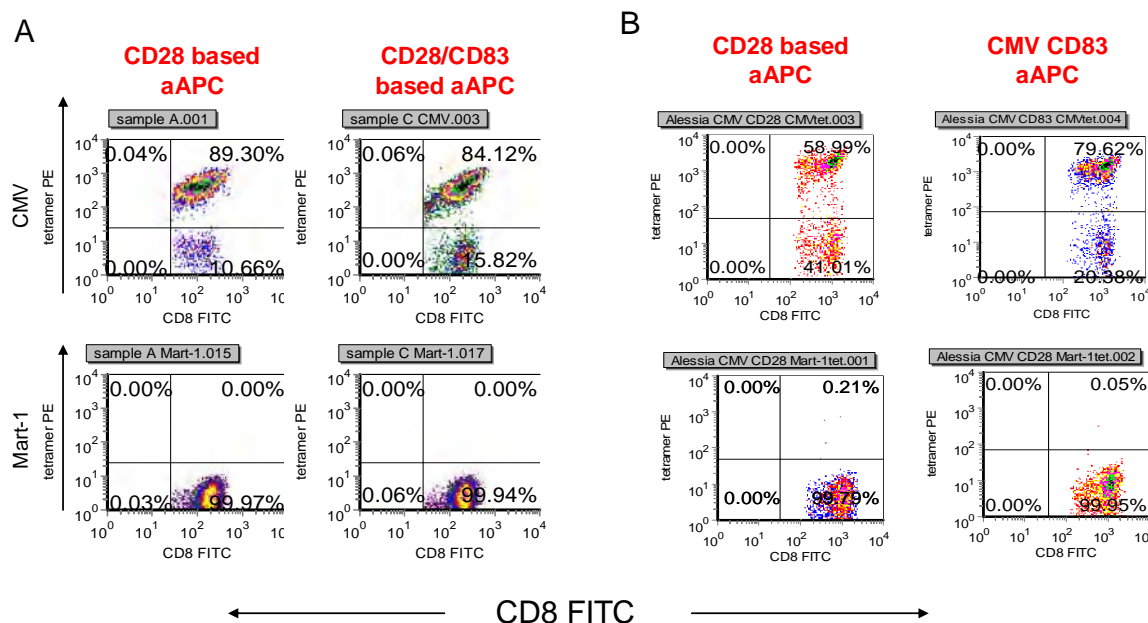
Figure 6: Analysis of EphA2 specific CTL induced with either anti-CD28- or B7.1-Ig- based aAPC



Legend: Figure 5 shows the analysis of the EphA2-specific CTL which were induced with B7.1-Ig based aAPC in comparison with EphA2-specific CTL induced with our current standard anti-CD28 based aAPC. In A is shown the tetramer analysis and in B is shown the result of the cytotoxic activity of the different EphA2-specific CTL lines determined with a standard ^{51}Cr -release assay. The effector target ratios are calculated according to the Total T cell number.

To evaluate the new CD83-Ig based aAPC we used the CMV system. We performed 3 experiments to generate CMV specific CTL from CD8+ T cells of healthy donors and compared the results with the use of our standard aAPC. The results show that the new aAPC are fully functional and capable of inducing antigen specific CTL.

Unfortunately, no major differences in specificity or expansion of the expanded T cells were detected when these new CD83-Ig based aAPC were compared with our current standard anti-CD28 based aAPC. Figure 7 shows one representative experiment. The fact that we were not able to major differences between the old and new aAPC could be due to the fact that the CMV system is such a strong antigen which does not require costimulation. Therefore, it is quite possible that we will detect differences when we will use these new aAPC to induce EphA2-specific CTL.

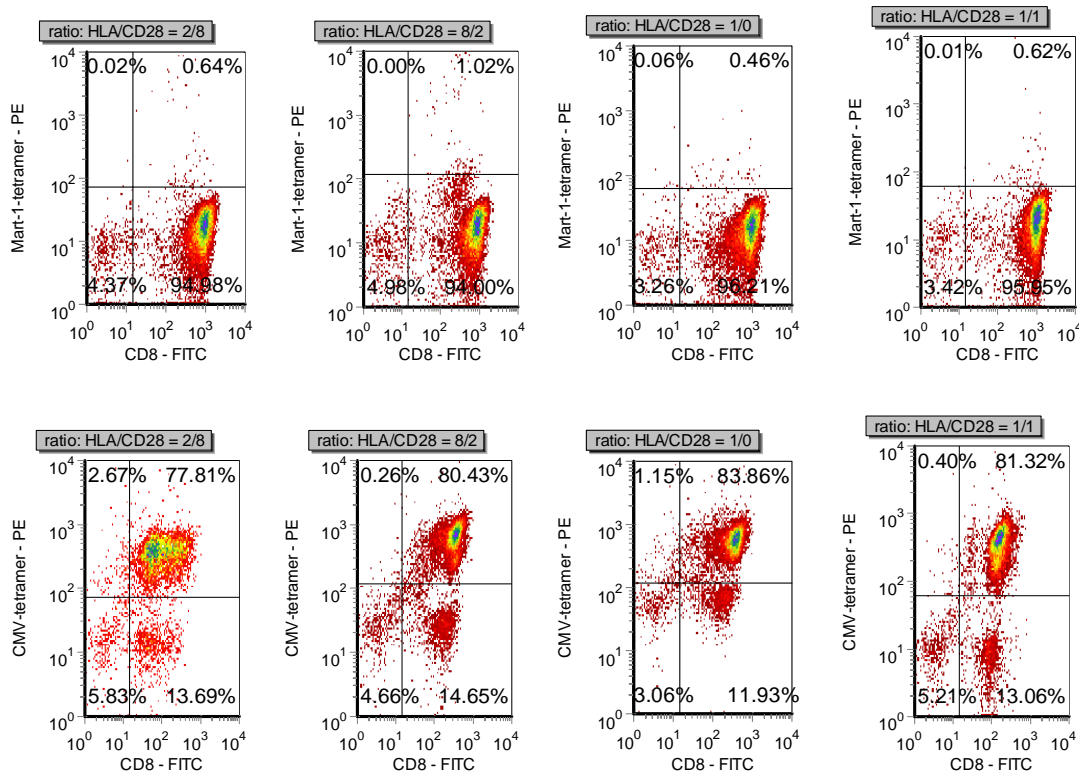
Figure 7: Tetramer analysis of 2nd generation aAPC induced CMV specific CTL

Legend: Figure 7 shows the dimer staining analysis of CMV specific CTL which were induced from CD8+ T cell of healthy donors using new aAPC made by coupling CD83-Ig +/- anti-CD28 together with HLA-A2-Ig onto magnetic beads. The result shows that all beads are functional, no major differences were seen between our standard anti-CD28 based aAPC and the new CD83-Ig based aAPC.

In addition to varying the type of costimulation we have also modified the ratio of signal 1 to signal 2 on our standard aAPC by preparing aAPC in the presence of different amounts of protein, as proposed in the statement of work. We have prepared a total of 4 different types of aAPC, by using the following ratio of HLA-A2-Ig to anti-CD28 (1:0, 8:2, 1:1, and 2:8). Figure 8 shows the results of our initial experiments, in which we used the different aAPC batches to generate CMV-specific CTL. While the CMV system is ideal to test the functionality of the new aAPC it seems it is too robust to identify differences in the stimulation capacity of the aAPC batches. Experiments to analyze the stimulation potential for EphA2-specific CTL are on going.

To overcome the problem of the limited expansion of the prostate cancer specific T cells we studied two approaches a) we used dimer and aAPC based antigen-specific T cell sorting to enrich, clone and expand prostate cancer-specific CTL and b) we studied the potential of aAPC immunization to activate and expand tumor-specific CTL *in vivo*.

Figure 8: Tetramer analysis of CMV specific CTL after induction with different aAPC

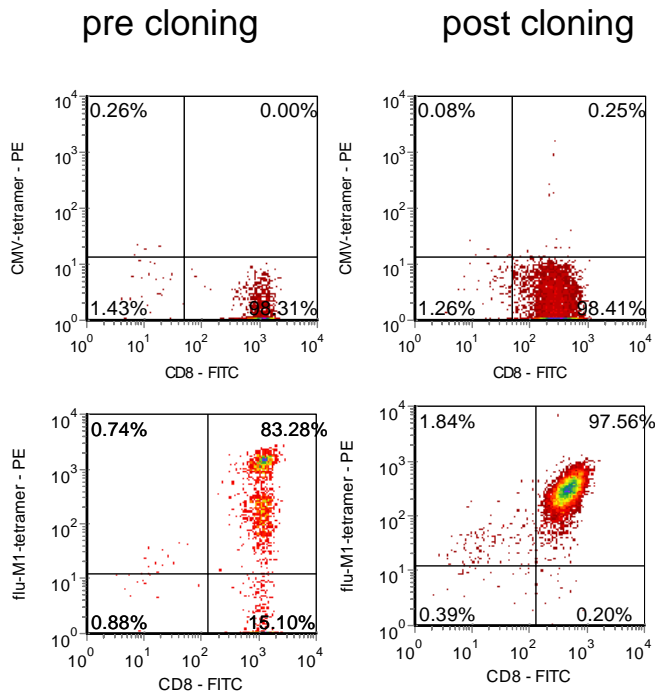


Legend: Figure 8 shows the CMV tetramer analysis of CMV specific CTL which were generated with aAPC which were made by coupling different amounts of HLA-A2-Ig and anti-CD28 onto a magnetic bead. The ration of signal 1 to signal 2 used for the aAPC preparation is shown in the title of each individual density plot. As negative control we stained the T cells with a PE labeled Mart-1 tetramer.

While we have expanded more than 30 potential T cell clones using a cloning protocol which we have previously successfully established using influenza M1 specific CTL (Figure 9), we were not able to generate EphA2-specific clones.

In our second approach we studied the effect of aAPC immunization to activate antigen-specific T cells *in vivo*. As schematically shown in Figure 10A, we have utilized a murine model in which we injected 5×10^5 genetically modified SIY-peptide expressing B16 tumor cells (B16.SIY) s.c. into B6 mice (day -7) to induce a solid tumor. Once the tumor had reached a size of ~5 mm diameter (day 0), 3×10^6 naïve SIY-specific T cells from 2C-TCR transgenic mice were adoptively transferred (i.v.). On days 1-3, we i.v. injected the mice with either 10^7 cognate or non-cognate aAPC and followed the tumor growth closely. As shown in Figure 10B, there was no statistically significant influence of treatment with non-cognate aAPC when compared to

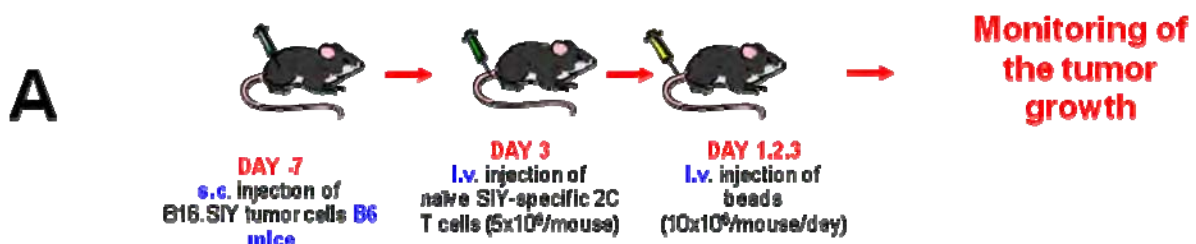
Figure 9: Tetramer analysis of an established flu-M1-specific T cell clone

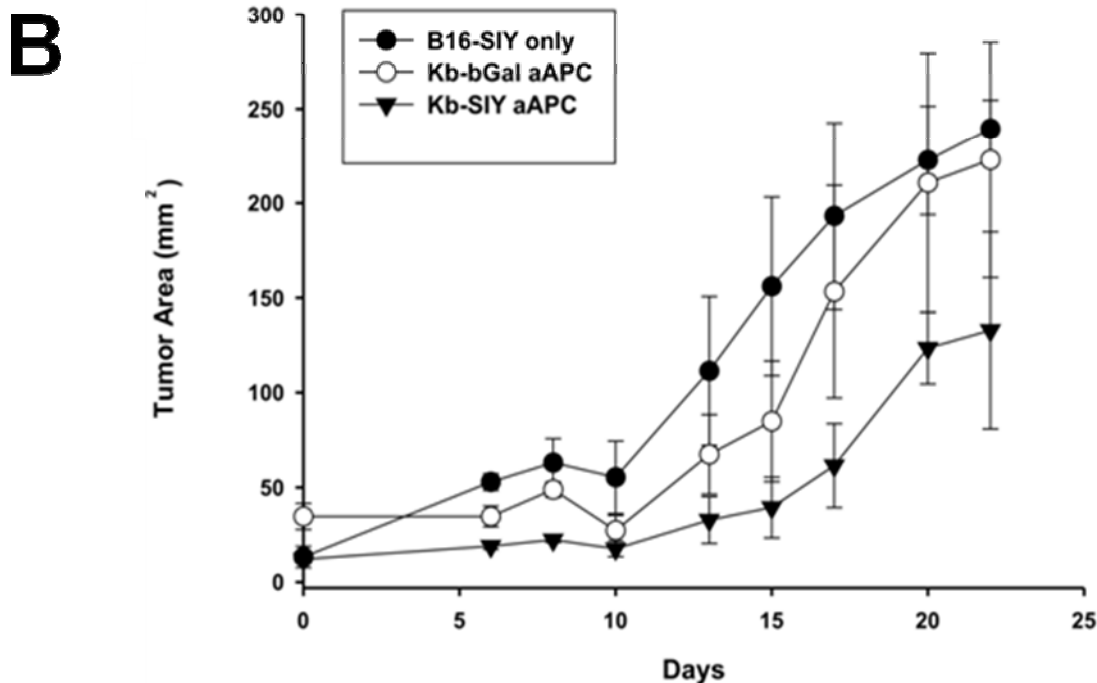


Legend: Figure 9 shows the tetramer analysis of flu-M1-specific CTL pre and post cloning. The left hand side shows analysis of the aAPC enriched bulk culture and on the right hand side is shown the analysis of one representative CTL clone. As negative control staining with the nonspecific CMV-tetramer was used.

untreated animals. In contrast, administration of cognate SIY-aAPC led to a significant reduction in tumor growth ($p=0.0039$) as compared to the control groups that were treated with either IL-2 alone or IL-2 in combination with non-cognate control aAPC.

Figure 10: aAPC immunization reduces tumor growth in a subcutaneous tumor treatment model





Legend: Figure 10 shows: (A) Schematic representation of the experimental protocol for aAPCs immunization in a subcutaneous tumor treatment model. The treatment groups were: mice challenged with B16.SIY melanoma and transferred with naïve SIY-specific T cells from T cell receptor transgenic 2C mice alone or in combination with non-cognate β -Gal aAPCs or cognate SIY aAPCs. (B) Immunization with SIY loaded aAPC significantly suppressed the growth of B16.SIY tumor. Mean tumor size for mice that have received tumor alone or with 2C transgenic CD8⁺ T cells and peptide aAPCs measured over 22 days at 2-3 day intervals. Tumor growth curves for mice treated with SIY-aAPC show statistically significant differences compared to mice that were untreated or treated with β -Gal loaded aAPCs. Error bars represent the standard error of the mean (n=5).

KEY RESEARCH ACCOMPLISHMENTS

- aAPC can be used to induce functional active prostate cancer specific CTL.
- Development of 2nd generation aAPC using multiple costimulatory molecules and different ratios of HLA-Ig to the costimulatory molecule.

- While some variations from donor to donor and antigen to antigen were observed it seems that the engagement of CD28 with his natural ligand B7.1-Ig, on 2nd generation aAPC, instead of a mAb specific for CD28 can result in better stimulation and expansion of antigen-specific CTL. More detailed experiments are necessary to confirm initial results.
- aAPC as well as dimer technology can be used to enrich for antigen specific CTL.
- aAPC immunization can be used to activate antigen specific T cells *in vivo*, thus this technology might be used to overcome limitations and hurdles related to *in vitro* culture of antigen-specific T cells such as limited expansion and GMP requirements for *in vitro* culture.

REPORTABLE OUTCOMES

A manuscript describing the use of peptide loaded aAPC for generation and cloning of prostate cancer specific CTL is in preparation. Another manuscript including the aAPC immunization data is currently submitted to the Journal "Cancer Research".

CONCLUSION

In summary, the performed experiments have resulted in the generation of prostate cancer specific CTL. We have further developed a large variety of 2nd generation aAPC which, while functional proven active; need to be further evaluated by using the low affinity prostate cancer specific antigens EphA2 and PSMA. These results will permit us to move effectively and clearly into evaluation of the *in vivo* efficacy of aAPC expanded prostate cancer specific T cells. In addition while our attempts to clone EphA2 specific CTL have so far not succeeded, we have studied the potential of aAPC immunization for *in vivo* activation of antigen specific T cells and found that aAPC can be used to stimulate tumor-specific T cells *in vivo* resulting in significant delay in tumor growth. Therefore, this new approach can be used to overcome the needs of large scale *in vitro* expansion of tumor specific T cells. Thus in future experiments we will test the possibility to adoptively transfer smaller numbers of antigen-specific CTL after short *in vitro* culture and then boost these cells *in vivo* using aAPC immunization. Such an approach has the additional advantage of limited *in vitro* expansion which will reduce cost and labor and more importantly prevent the expanded T cells from exhaustion due to long term *in vitro* culture.

REFERENCE

1. Oelke, M., M. V. Maus, D. Didiano, C. H. June, A. Mackensen, and J. P. Schneck. 2003. Ex vivo induction and expansion of antigen-specific cytotoxic T cells by HLA-Ig-coated artificial antigen-presenting cells. *Nat Med* 9:619.

2. Oelke, M., and J. P. Schneck. 2004. HLA-Ig-based artificial antigen-presenting cells: setting the terms of engagement. *Clin Immunol* 110:243.